FINAL REPORT

SCAG Parking Price Model Development

Prepared for:

Southern California Association of Governments

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Prepared by:
TJKM Transportation Consultants
5960 Inglewood Drive, Suite 100
Pleasanton CA 94588-8535
Tel: 925.463.0611
Fax: 925.463.3690

In association with INRO Solutions Inc.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION AND SUMMARY

Introduction

As the designated Metropolitan Planning Organization, SCAG (the Southern California Association of Governments) is mandated by the federal government to research and draw up plans for transportation, growth management, hazardous waste management, and air quality.

In order to analyze different development and transportation plans, SCAG uses a regional demand forecasting model. This model uses a predetermined parking price (price) for each zone developed by Caltrans in 1990. The parking prices are used in the mode choice model as a parameter. Since 1990 there have been great changes in the US economy, which certainly affects travel behavior and mode choice decisions. Thus it is necessary to update all of the information and data used in the current model to estimate utility functions, and to provide a new parking price function for the SCAG regional model.

The TJKM Team (TJKM Transportation Consultants and INRO Consultants) was retained by SCAG to develop a new parking model based on new SCAG socio-economic data, land use data and the new parking survey.

The parking price model can be considered a component of the SCAG regional model. However based on the consideration of various factors including the complexity of the SCAG regional model calibration, it was decided to develop an independent model serving as an external routine as is the case with the existing SCAG parking price model.

The basic requirements for the model are stated as follows:

1. Be able to provide parking prices at the aggregate TAZ (traffic analysis zones) level
2. Be sensitive to socio-economic and land use characteristics, as well as policy variables
3. Use data that are reasonably available and forecastable by SCAG staff
4. Be reliable as a forecasting tool and easy to use
5. Reflect essential parking price behaviors as can be suggested from the literature and
6. Be validated with the observable data

This is a very challenging problem to solve. Basically, for this project, there is no existing parking demand data from survey, no on-street parking supply and demand survey, no historical data for study area, and no subsidy information. The socio-economic data are TAZ-based while the parking supply survey data is facility-based, which requires the establishment of a conformity process to relate the TAZ information with the facility information. We found that the parking price varies within a zone, and that actual price paid varies from posted prices. This is because many travelers, especially commuters to work, have subsidized parking available and may not have to pay for parking. With consideration of all these factors, it was decided to develop a TAZ-based parking price model that uses the SCAG socio-economic data and the recent SCAG parking facility survey as validation information.

With this information, TJKM successfully developed a TAZ-based parking price model that satisfies the stated requirements with the most recent technology.

Project Area

Over the past three decades, the Southern California Association of Governments has evolved as the largest of nearly 700 councils of government in the United States, functioning as the Metropolitan Planning Organization for six counties: Los Angeles, Orange, San Bernardino, Riverside, Ventura and Imperial. The region encompasses a population exceeding 15 million persons in an area of more than 38,000 square miles. The project area for this project is seen in Figure 1 (a GIS TAZ plot). In the current SCAG model, there are 3191 TAZ. The parking price model is developed based on these TAZs.

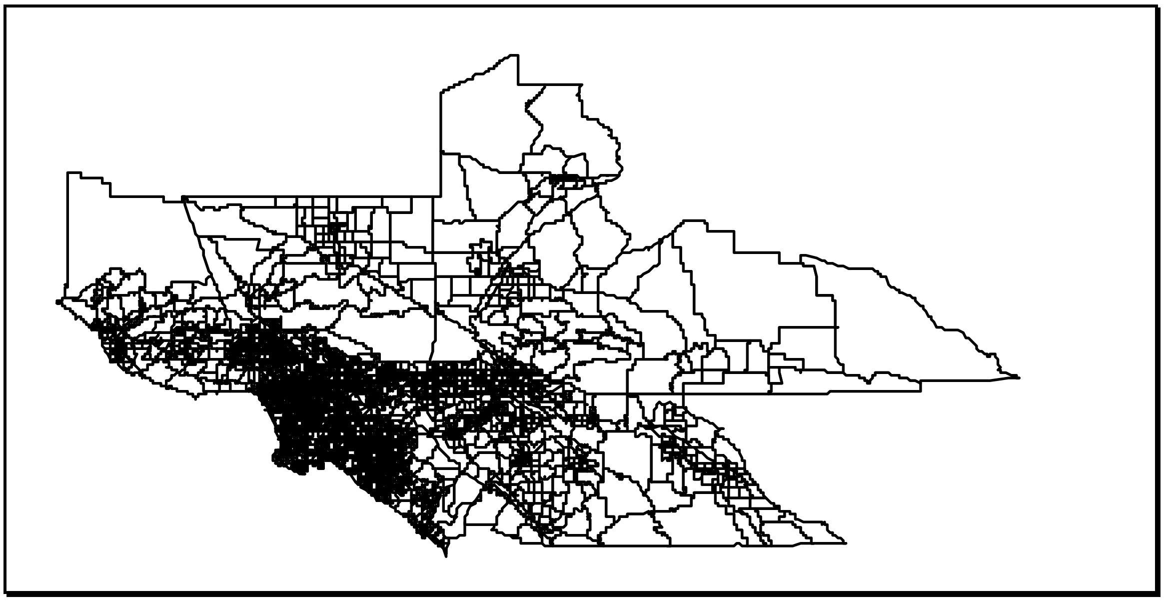

FIGURE 1 - SCAG GIS MAP FOR THE PROJECT

Methodology

TJKM used SCAG socio-economic data, land use data and the recent SCAG parking facility supply survey to develop an integrated SCAG parking database in both MS Access and the GIS ArcView. Via the ODBC data connection, TJKM used both statistical and Data Mining software to explore the database to find statistical relationships including the identification of significant variables and functional forms. Our results are finally developed, analyzed and presented in the GIS environment.

In addition TJKM conducted a literature review to identify current best practices in the US. This review serves as a theoretical guidance to the modeling development to ensure that this model is a state-of-art product given the data availability and the SCAG requirements.

It is important to indicate that the final SCAG parking price model is a compromised effort meeting these stated requirements.

Summary

TJKM has successfully accomplished the following tasks:

1. Conducted five conferences with the SCAG modeling staff with many practical ideas and suggestions for possible improvements;
2. Developed SCAG parking price database in GIS and MS Access;
3. Processed the SCAG parking price database with many corrections and necessary adjustments;
4. Analyzed the SCAG parking price database with several findings;
5. Developed a operational SCAG parking model;
6. Developed a future price forecasting method with the difference method and a probit model; and
7. Completed this technical report documenting the modeling process.

The basic findings and results are:

1. The relationships between parking prices of these parking facilities and their capacities are found to be significant, with higher priced facilities having more parking spaces available;
2. The statistical R-Square could be improved more with land use data than the socio economic data;
3. The statistical R-Square could be improved with variables that are available now but may not be accurately forecasted for the future;
4. Although there are fourteen types of prices in the SCAG parking survey, only the daily maximum prices with 823 records (among 835 records) is suitable as a dependent variable for model development;
5. The daily maximum price at each parking facility price is used to form the influence area prices for all the TAZs. There are 358 TAZs with positive prices and positive capacities out of 3191 zones;
6. The TAZ-based daily average price model uses service density and the retail density as two explanatory variables with a R-Square greater than 0.5. These two variables are found to be statistically significant based on the current SCAG data set;
7. The forecasting method is used to predict the price changes instead of the direct price estimation.
8. For those zones with no price data or zero price, a probit model is used to determine the probability for future occurrence of paid parking on these two variables as well.

The deliverables of this project are provided as follows:

1. The revised parking facility and TAZ-based parking price GIS files;
2. The TAZ-based parking model in Excel with existing and future year prices and
3. This final report.

LITERATURE REVIEW

Review of Previous Parking Price Models

In the past, several Metropolitan Planning Organizations (MPO) developed parking price models as part of their regional travel demand models. Parking price models support mode choice models that use parking price as one of the explanatory variables in determining the proportions of auto and transit trips. Models developed for the Metropolitan Planning Organizations (MPOs) of Denver (Colorado), Houston (Texas), Dallas/Fort Worth (Texas), Pittsburgh (Pennsylvania), and Chicago (Illinois) are the more extensive ones. Review of the models is summarized as follows:

1. All of the existing models are in the form of linear regression.
2. Variables of zonal employment density were used in most of these models as the explanatory variables for predicting parking prices. The Chicago model tested the use of trip attraction density (i.e., number of vehicles attracted to a TAZ per unit area).
3. The Denver Model, following the Houston and Dallas/Fort Worth models, used the concept of Influence Area (e.g., an area within 0.2 mile radius of the TAZ centroid) to estimate the average parking prices for TAZs in the analysis. The use of influence area allows the model to account for the parking demand characteristics of the surrounding areas of a TAZ, which can be justified by the observation that parking facilities are often located on streets at the borders of TAZs and drivers may park their car in a zone next to the one in which they work.
4. Except for the Houston and Denver models, none of the existing models considered the effect of a parking supply on parking price. In the Denver model, the inclusion of parking supply variable in the model necessitated the creation of a parking supply model for future forecasting. An extensive parking survey was conducted for the purpose of building the parking supply model.
5. Except for the Denver model, most of the models estimated the average posted parking price, not the out-of-pocket parking price paid by the driver. In reality, some drivers received free parking or subsidy. The average out-of-pocket parking price is thus expected to be lower than the average posted parking charge. However, estimation of out-of-pocket parking price requires a survey of drivers regarding if free parking and subsidy are provided.
6. Most of the above models were developed from a small set of samples (e.g., Dallas/Fort Worth model contains 18 TAZs, Denver 29, Chicago 33), which were collected in the CBD. These models used a threshold employment level to determine if the model will be applied to a specific TAZ. Such a cutoff point allows the model developed from the CBD to be applied to the whole region without forecasting parking price for every TAZ.

The Bay Area MTC Model (MTC, 1998)

The MTC parking price model is in fact a ratio-based method instead of a regression-based method. The MTC demand models were estimated using nominal, or posted parking prices as opposed to actual parking prices. Actual parking prices would be the average parking price paid by a consumer, weighted by those who are subsidized by their employer and those who are not subsidized by their employer. For peak period parking price, the monthly posted parking price is divided by 22 days per month to derive an average workday parking price. The average workday parking price is then divided by 8 hours to derive an average peak hour parking price per hour in 1990 cents. In the home-based work mode choice model application, the per hour charge is multiplied by 8 hours, then divided by 2, to derive a per vehicle trip charge. Next, the per vehicle trip charge is divided by the vehicle occupancy so that parking prices are equally distributed between vehicle drivers and passengers.

Based on the base years 1990 and 1998, forecast years 2000, 2010 and 2020 peak and off-peak hour parking prices in the MTC 1099 zone system are computed with a ratio method.

The MTC assumption for parking prices is that they will increase, in real terms, between one and two percent per year between 1990 and 2020. The core of downtown Oakland, Berkeley and San Jose are assumed to grow by two percent per year between 1990 and 2020; in all other areas, by one percent. In addition, Palo Alto and Stanford, which were assumed to have free peak and off-peak parking in 1990, are assumed to have per hour parking charges roughly equivalent to downtown Berkeley in future year forecasts.

MTC staff periodically inventory parking garages throughout the Bay Area to monitor trends in parking prices. MTC staff updated this parking price inventory in summer 1998. Future parking price forecast assumptions will be revisited based on the updated inventory.

Possible Variables

TJKM conducted a detailed analysis of these parking price literature to determine the relevant variables in the determination of the parking price. There were several considerations for variables in the literature. Some of them are location-dependent while others are accessibility-related.

Parking demand and supply will interact towards equilibrium. This has been observed in many of our studies in addition to the Denver study. Trip purpose and transportation modes such as Park-and-Ride have an effect on parking demand in terms of duration time and walking distance to the parking lot. Ownership and function of parking lots and garages are important variables to be considered in the development of the parking price model. The literature suggests the following in developing a parking price model.

1. The service cost such as the average time for the travel purpose (shopping , working, etc.) at destination may effect the parking prices.
2. The travel volume at the destination is another variable in the well-known "Pollaczek-Kintchine" formula (See Norbert Oppenheim, Urban Travel Demand Modeling, 1995 for more).
3. Land use information (as destination and origin related) like CBD and suburban, financial districts, floor space and service intensity are all good indicators for price (Wen Long Yue et al., 1998).
4. The auto and transit accessibility at the destination may play an important role in the parking price.
5. The parking period such as AM Peak and Off Peak would effect the parking price as well due to the demand patterns.

The above discussion indicates a necessity for in-depth investigation. The variables presented here would need to be investigated based on the SCAG current data inventory to see if there are any co-relationships among the potential variables. Then the functional forms need to be established with a good calibration.

DATABASE DEVELOPMENT

The TJKM used GIS and database technology to store, study, review and report the results, and to compare them with model results using both tabular and mapping outputs. This allowed us to quickly identify the potential errors and suggest various ways for improving model equations and results. The X and Y coordinate-based information is provided in the SCAG GIS database allowing us to easily aggregate the point-based information into TAZ-based information. Without the help from GIS technology, it would be difficult and inefficient to carry out the work in a timely fashion.

Data Received

The parking price models developed in this study utilize data supplied by SCAG. Sets of data received are described in the following.

Parking Survey

The parking survey was performed for SCAG by another contractor. The survey data set was received in a Microsoft Access database. The original database contains 835 records of parking facilities. Information on parking prices was mainly identified through the following data items: minimum price, minimum time, hourly price, and daily maximum price. Minimum price is the amount of money required to enter the parking facility. Minimum time is the period of time within which the vehicle can park for paying just the minimum price. Hourly price by definition is the amount of incremental parking price when a vehicle parks for an additional hour over the minimum time. According to the survey data, only 16 parking facilities posted hourly price and used it in their pricing scheme. Hourly price of the rest of the facilities are all zero. Daily maximum price is the maximum amount charged if a vehicle parks for an extended period of time during the day (e.g., over eight hours).

The original survey data received from SCAG contains coding inconsistencies and missing data. The most crucial missing data items are minimum prices and daily maximum prices. 158 records contain no minimum prices and 52 records contain no daily maximum. Among them, 17 records miss both minimum and daily maximum prices. TJKM performed extensive data cleaning to recover the missing information and ensure data quality. The first step in recovering data was to retrieve information recorded in the "Comments" field, which was used by the interviewers to describe pricing information in texts. Missing prices of 7 records were recovered with information found in the "Comments" field. If a parking facility record contains only daily maximum prices but no minimum price and no minimum time, it indicates that the facility charged a flat-rate in the amount of the daily maximum. For such records, the minimum price column was filled with the amount of daily maximum to be consistent with other flat-rate facilities. On the other hand, there are records of facilities that have only minimum price and minimum time (or hourly price) but no daily maximum. The daily maximum prices of such records were recovered in two ways. First, it was assumed that the daily maximum of the facility with missing data is the same as those of the facilities that are located in the close vicinity. Second, if no parking facilities could be found in the vicinity, it was assumed that the daily maximum price was determined based on an eight hour parking duration. (i.e., daily maximum = minimum price * eight hours / minimum time in hours). For records with neither minimum prices nor daily maximum and no information can be recovered from the "Comments" field, such records would later be excluded from the analysis. There were 12 such records.

The parking survey also contains information on the capacity (available spaces) of each facility. Twenty five (25) records do not contain information on capacity. The missing capacity information could not be recovered.

Parking Facility ArcView Shape File

An ArcView Shape file of the geo-coded parking facilities was also received from SCAG. Figure 2 shows the 835 parking facilities surveyed in the Southern California region. Fifteen (15) records in the original parking survey (in the Microsoft Access database) were not included in the shape file due to missing address information. In addition, two major geo-coding errors were identified in the shape file. First, a group of 12 parking facilities that were supposed to be located on Grand Avenue in downtown Los Angeles spanning from 3rd street to 12th Street was mistakenly geo-coded west of the City of Long Beach. Another group of four facilities that were supposed to be located on Flower and Hill Avenues in downtown Los Angeles was geo-coded on two streets of the same names in the south of Santa Monica. These records were later geo-coded back to the correct locations-based on the Thomas Brothers street Shape file.

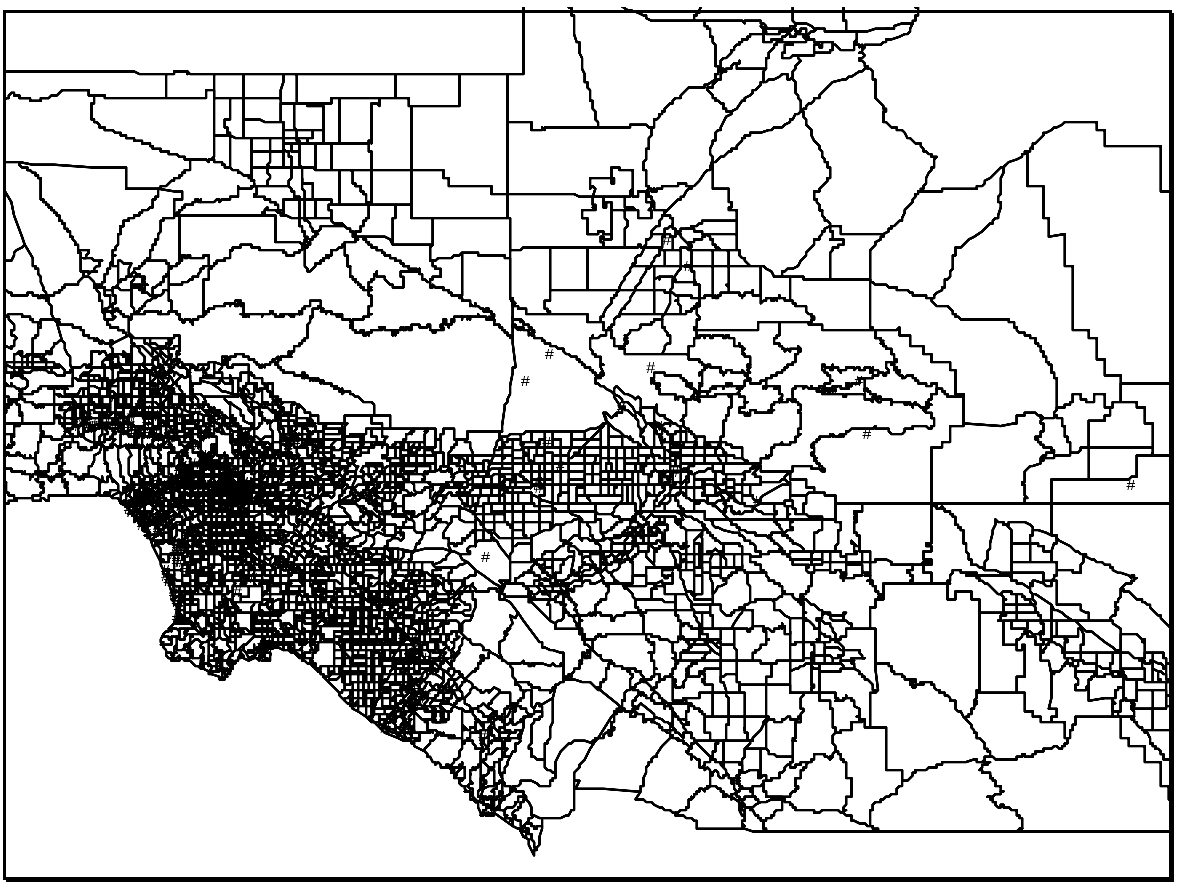

FIGURE 2 - PARKING FACILITIES FROM THE SCAG PARKING SURVEY

TAZ ArcView Shape file

A TAZ shape file was received from SCAG. There are 3191 zones in this file. The set of TAZs was created in 1999 and is currently used in SCAG's travel demand models.

Land Use ArcView Shape File

Land use is one of the important determinants of parking generation. Currently, the only land use file available from SCAG was created in 1993. Although land use designation in most of the SCAG regions has been changed since then, in the well-developed areas (e.g., downtown LA) change of land use is limited. Thus, the land use file was retained for the purpose of identifying the portions of different land uses in each TAZ.

Thomas Brothers ArcView Shape Files

The Thomas Brothers ArcView Shape files of the streets in entire SCAG region were obtained from SCAG to examine if parking facilities were geo-coded properly. In addition, shape files of city and county boundaries were also used for the same purposes.

TAZ-Based Socio-Economic Data

TAZ-based socio-economic variables representing the year of 1997 were obtained from SCAG. Future forecasts of these variables representing years of 2010 and 2025 were also supplied by SCAG. These variables are used in this study to estimate parking demand each TAZ.

TAZ-Based Vehicle Volume by Time Periods

The estimated vehicle volumes leaving and entering each TAZ at three different time periods of the day were derived from the current SCAG's regional travel model. The three time periods of the day are morning peak hour, mid-day, and evening peak hour. The volumes were also used in this study to estimate parking demand. In addition to the estimated vehicle volume of 1997, forecasted vehicle volumes of 2010 and 2025 were also obtained from SCAG.

TAZ-Based Data Used for Mode Choice Modeling

SCAG developed a set of TAZ-based variables for use as input variables to the mode choice module of its regional travel model. These variables are essentially socio-economic variables.

Block-Based Area Type Data

SCAG provided a set of block-based shape files, which is different from the land use data. This set of block-based files contain the revised variable of AREATYPE, which is used to identify the location and development patterns for each TAZ. The area types are classified as core area, CBD, UBD, urban, suburban, rural, and mountain area.

Data Created

Using data supplied by SCAG, additional variables were created in order to better estimate the potential parking demand of a TAZ.

Employment Density

Because the sizes of TAZs vary widely in the SCAG zoning system, the use of aggregated zonal socio-economic data in a model does not correctly estimate the actual magnitude of parking demand at a TAZ. For example, a large TAZ in the rural area may have the same number of total employment as one in the downtown area. However, TAZs in downtown are smaller, usually only the size of a few blocks. Density-types of variables were developed to address this fallacy. Zonal employment variables (i.e., service, retail, other, and total employment) were divided by the acreage of a TAZ to derive the employment density variables.

Zonal Accessibility Indicators

It is expected that the level of automobile and transit accessibility of a zone may play a role in the pricing mechanism of parking. Zonal accessibility indicators were developed based on SCAG's highway and transit planning networks. The formula used to determine accessibility level of a specific mode is as follows:

$$ACC_{im} = \sum_j T_{ij} D_{ijm} / \sum_j D_{ijm}$$

where,
ACC_{im} = Accessibility level of TAZ i by mode m;
D_{ijm} = Number of trips from TAZ i to TAZ j by mode m;
T_{ijm} = Travel impendence by mode m from TAZ i to TAZ j.

Accessibility levels by five different type of modes were estimated: drive-alone, walk-to-local-transit, walk-to-express-transit, auto-to-local-transit, and auto-to-express-transit.

Land Use and TAZ Intersection

In order to estimate the areas of different land uses within a TAZ, the 1993 land use shape file was overlaid on top of the TAZ shape and the operation of intersect was performed. The intersect process computes the geometric intersection of the two shape files so that the total area of a specific land use within a TAZ can be estimated.

TAZ Influence Area

In this study, to avoid the arbitrary allocation of the parking facilities located in the boundaries to TAZs, a TAZ Influence Area is used. It is defined as an area whose boundary is 0.125 mile beyond the original boundary of the TAZ. Figure 3 illustrates the concept of a TAZ Influence Area.

The shape file of TAZ Influence Areas was overlaid on top of TAZ shape file to estimate the percent area of a TAZ lying inside the influence area of the neighboring TAZ. The operation is needed for the estimation of average (daily) parking price of a TAZ influence area (see next section for the mathematical definition).

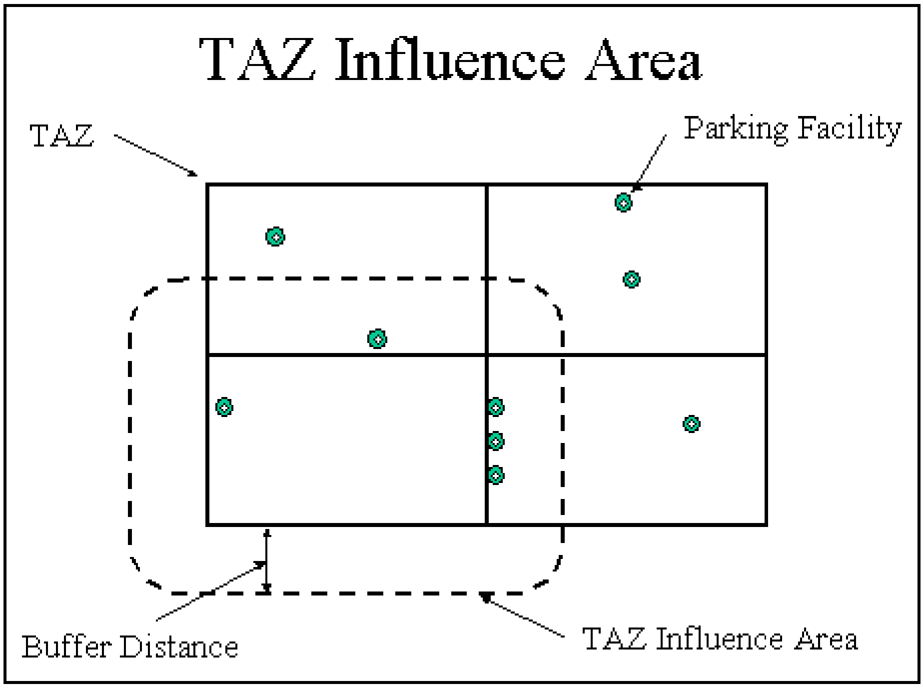

FIGURE 3 - CONCEPT OF TAZ INFLUENCE AREA

Influence Area Price (IAP)

The determination of the average daily parking price of each zone is based on the posted daily maximum parking price and parking spaces of all paid-parking facilities. In addition, many parking facilities are actually located on streets that are borders of two or more TAZs. These facilities usually serve more than one TAZ. Thus, the determination of the average parking price of a TAZ should take into account parking facilities that are located at a certain distance extending from the TAZ's boundary. Such a concept was termed Influence Area and employed in previous parking price models. The procedure of determining the average parking price of a TAZ Influence Area is described below.

1. Determine the average daily maximum parking price per space for each TAZ.

A survey of paid parking facilities in the SCAG region was conducted. The survey contains information on daily maximum parking price and the number of spaces of each parking facility. At this stage, the calculation of average daily maximum parking price only takes into account those parking facilities located within the boundary of the TAZ. The average daily (maximum) parking price per space of a TAZ is determined using the following equation:

$$TC_z = \sum_{f \in Z_z} P_f S_f \Big/ \sum_{f \in Z_z} S_f$$

where,

TC_z = average daily (maximum) parking price of TAZ z;
Z_z = set of parking facilities within TAZ z;
P_f = daily maximum parking price of parking *facility* f;
S_f = number of parking spaces of parking facility f.

2. Estimate the average daily maximum parking price of a TAZ Influence Area.

The average daily (maximum) parking price of a TAZ influence Area (IAP_z) is calculated based on the following equation:

$$IAP_z = \sum_{i \in I} p_i A_i TC_i / \sum_{i \in I} p_i A_i$$

where,

IAP_z = average daily maximum parking price of the Influence Area of TAZ z;
I = a set of TAZs within the Influence Area of TAZ z;
p_i = a percent area of TAZ i lying inside the influence area of TAZ z;
A_i = an acreage of TAZ i;
TC_i = an average daily (maximum) parking price of TAZ i.

Influence Area Parking Capacity

The SCAG parking survey contains information about the capacity (i.e., available spaces) of each paid parking facility. Parking spaces available within each TAZ influence area of a TAZ ($IACAP_z$) is determined by the following equation:

$$IACAP_z = \sum_{i \in I} CAP_i * p_i$$

where

$IACAP_z$ = total paid parking space available within the Influence Area of TAZ z;
I = a set of TAZs within the Influence Area of TAZ z;
CAP_i = an average paid parking spaces within TAZ I;
p_i = a percent area of TAZ i lying inside the influence area of TAZ z.

BASIC FINDINGS OF THE DATA BASE

In this study TJKM performed extensive data processing to correct errors and make necessary adjustments based on the "Comment" information in the original database from SCAG. This data processing was iterative in nature based on our findings and observations. In this section, several basic findings are provided.

Basic Statistics

There are two types of data statistics, that is, parking facility-based and TAZ-based. TJKM revised and repaired the parking facility database with the following summary in Table 1. In fact there are 781 or 758 records with price information, both non-zero daily maximum and capacities respectively. The daily maximum price and parking capacities are the best data source for our model. Other data (e.g., minimum price and hourly price) were used as supplementary sources to recover missing daily maximum parking prices.

Based on this information, TJKM computed the TAZ-based IAP prices (i.e., average daily parking price of a TAZ influence area) and the TAZ-based IACAP capacities (i.e., total paid parking space available within the Influence Area of TAZ). Thus there are 358 TAZ records with positive prices and the 363 with positive capabilities. The number of records with both positive prices and capacities is 356.

TABLE 1: RECORDS WITH INFORMATION FROM THE SCAG SURVEY DATABASE (FACILITY)

Name (835 records)	Records	Name (835)	Records
Monthly High Price	146	Other Price 1	3
Monthly Low Price	144	Other Price 2	1
Early Bird Price	42	Other Price 3	11
Daily Maximum Price	823	Free With Validation (Hours)	42
Minimum Price	823	Free With Validation (Minutes)	45
Min Time	642	SatSun (Yes)	121
Evening Price	148	MonFri (Yes)	787
Monthly L Price	159	Parking Capacity	809
Monthly H Price	161	Operator	657
Valet Price	15	Facility Type	760
Group Price(Daily)	1	City	835
Group Price(Month)	1	Sub-region Name	835
Hourly	16	ZIP	832

SCAG Original Park Price vs IAP

In the current SCAG regional model, there exists a variable named PARKCOST, calculated by Caltrans. The variable was used by SCAG as one of the mode choice variables. Figure 6 shows the relationship between the SCAG original prices (PARKCOST/100) and the TAZ-based prices (IAP) based on the most recent facility parking price survey. As can be seen, there are some discrepancies of some zones where there are zeros of either the TAZ-based IAP or the SCAG original prices. However the value ranges of these two prices are generally consistent with each other. This observation confirms:

1. The current SCAG regional model needs to be updated with the new TAZ-based IAP

2. The new TAZ-based IAP are in a reasonable range as validated by reviewing the original SCAG parking prices.

Based on the discussion with SCAG and our investigation, it was decided to use the TAZ-based IAP for our model development.

TAZ -Based IAP vs Facility Capabilities

TJKM used a data mining technology to find other potential variables such as the facility capacities that would influence the TAZ-based IAP.
Table 2 shows statistics of both TAZ-based prices (F_IAP) and capacities (F_IACAP) with the number of records = 356, R2 = 0.47, and the standard deviation= 2.2. Figure 5 shows the scatter-gram between the two variables.

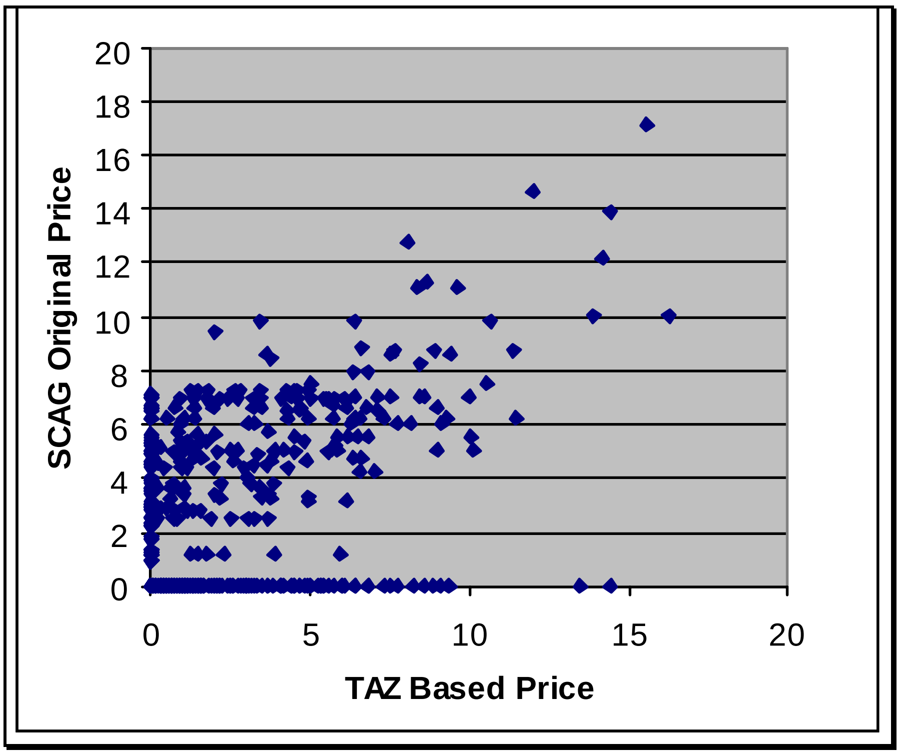

FIGURE 4 - SCAG ORIGINAL PRICES VS THE TAZ-BASED PRICES (IAP) IN DOLLARS

TABLE 2: STATISTICS FOR BOTH TAZ-BASED PRICES (F_IAP) AND CAPACITIES (F_IACAP)

Numerical and integer attributes:	Values	Mean	Std.Dev	Min	Max	Range	Median
F_IAP	356	3.556	3.13	0.003987	16.26	16.26	2.713
F_IACAP	356	1734	2967	5.301	3.029e+004	3.028e+004	696.7

It is observed that in addition to the service and retail employment density, TAZ-based parking capacity is highly correlated with the TAZ-based IAP as follows:

$$IAP_{z}=0.634+0.087*SQ\_IACAP_{z}$$

where

IAP_z = the IAP (average daily maximum parking price in dollars) of the influence area of TAZ z

SQ_LACAP_z = square root of total paid parking space density of the inference area of TAZ z.

Contrary to the conventional economic theory that states the higher the supply (i.e., parking capacity) the lower the price, the reverse is observed here. In fact, in this parking facility survey, only off-street parking facilities were surveyed. According to the ITE's parking space requirement, the larger parking spaces are required for larger spaces of the various types of the business areas. Due to the higher investment for these parking facilities, we found that the larger the parking facility is the higher the parking price will be. Thus, in the case of off-street paid parking, capacity is a positive indicator of demand for the parking.

Currently, SCAG has no future data of the parking spaces for all the TAZs. Thus this variable is not predictable by SCAG. However, it is possible, in the future, that SCAG can provide an estimation of floor spaces provided for various business types. Using the ITE parking requirement and jurisdiction requirements, the future parking capacity can be estimated.

It is important to note that in addition to ITE and the Urban Land Institute, TJKM finds that different jurisdictions may have different parking requirements in Southern California, as seen in Table 3. It is noted that the parking requirements of ITE and ULI are different for retail spaces and the house units. With respect of the these cities, the parking requirements for the employment related space (that is, industrial, office, retail) are similar, while the city of Glendale requires higher parking spaces than any other cities.

Facility-Based Parking Prices by Area Type

It is also important to understand the distribution of facility parking prices by seven area types. Parking price statistics (see Table 4) are computed for each area type for all the positive parking prices. As can be seen, most TAZs with positive parking prices are located in the CBD (Central Business District), while there are seven parking facilities in the Mountain Area such as the public parking spaces. Interestingly, the most expensive parking facilities with a $30.00 maximum daily price are in both Rural Area and Mountain Area (i.e., a special event venue in San Bernardino County). The minimum parking price is $0.75 in the Urban Business District.

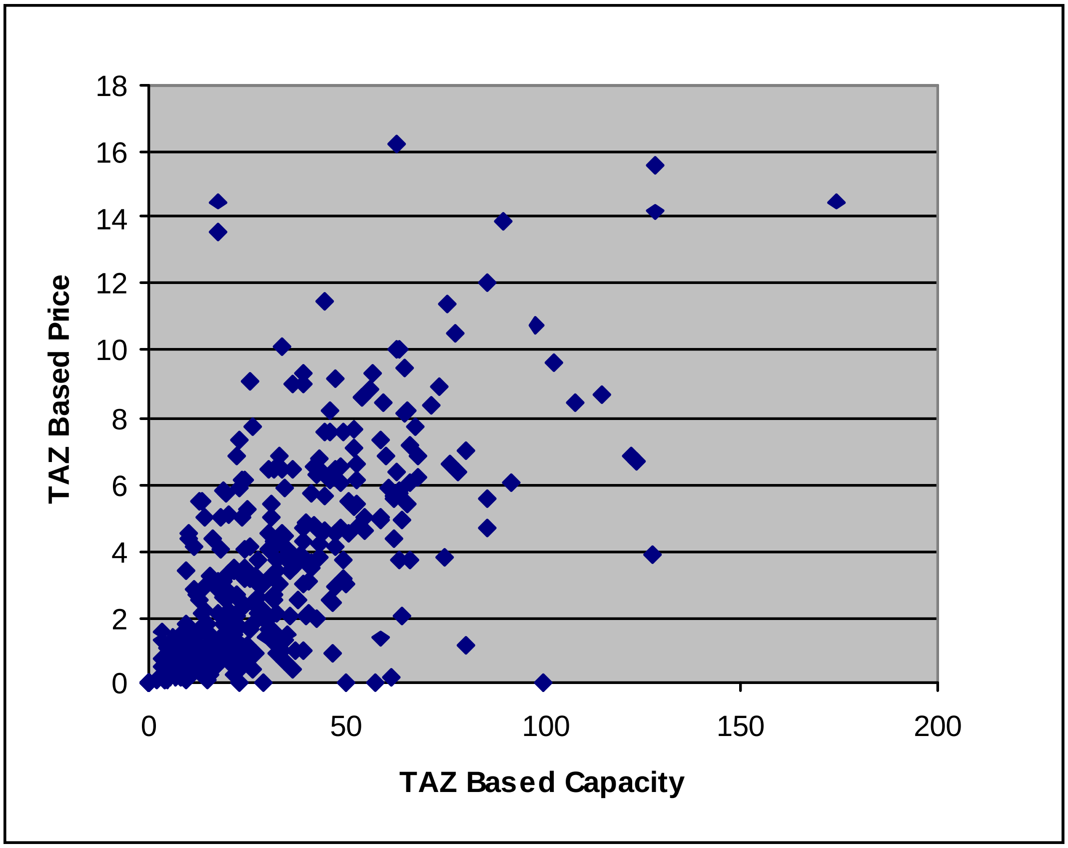

FIGURE 5 - TAZ-BASED PRICE VS TAZ-BASED CAPACITY

TABLE 3: PARKING CAPACITY REQUIREMENTS IN SOUTHERN CALIFORNIA

Land Use	Requirement
Institute of Transportation Engineers (ITE) Rates	
Retail	3.23 per 1000 GLA
Housing / Multiunit apts	0.88 per unit
Urban Land Institute (ULI) Rates	
Retail	4 per 1000 GLA
Housing / Multiunit apts	1.1 per unit
City of Los Angeles	
Industrial	2 per 1000 GLA
Office	3 per 1000 LGA
Retail	4 per 1000 GLA
Housing: Studio	1 per unit
1 bedroom	1 per unit
2 bedroom	1 per unit
3 bedroom	1.25 per unit
City of Glendale	
Industrial	2 per 1000 GLA
Office	3 per 1000 GLA
Retail	4 per 1000 GLA
Housing:	
1 bedroom	2.0 per unit
2 bedroom	2.0 per unit
3 bedroom	2.5 per unit
City of Long Beach	
Industrial	2 per 1000 GLA
Office	4 per 1000 GLA
Retail	4 to 5 per 1000 GLA
Housing: studios	1.0 per unit
1 bedroom	1.5 per unit
2 bedroom	2.0 per unit
3 bedroom	2.0 per unit
City of Santa Monica	
No special provisions for downtown district	
Retail - General	3.33 per 1000 GLA
Housing: Studio	1 per unit
1 bedroom	1 per unit
2 bedroom	1.5 per unit
City of Fullerton	
Industrial	1 per 1000 GLA
Office	4 per 1000 GLA
Retail	4 per 1000 GLA
Housing: studio	1.25 per unit
1 bedroom	1.5 per unit
2 bedroom	1.75 per unit
3 bedroom	2.0 per unit
City of Burbank	
Industrial	2 per 1000 GLA
Office	3 per 1000 GLA
Retail stores	3.3 per 1000 GLA
Housing:	
1 bedroom	1.25 per unit
2 bedroom	1.5 per unit
3 bedroom	1.75 per unit

TABLE 4: PARKING PRICE STATISTICS BY AREA TYPE

Area Type	Code	Count	Mean	Min	Max	Std
Core Area	1	57	14.45	3.75	27.00	7.12
Central Business District	2	360	8.29	1.25	27.00	5.15
Urban Business District	3	252	7.79	0.75	26.75	4.71
Urban Area	4	126	6.75	1.00	18.00	3.48
Suburban Area	5	26	10.15	3.00	18.00	4.44
Rural Area	6	11	6.09	1.00	30.00	8.23
Mountain Area	7	16	5.56	1.00	30.00	6.84

PARKING PRICE MODELS

General Methodology

Based on the above analysis, the objective of the parking price modeling is to estimate a mathematical relationship between IAP (the average daily maximum parking price of a TAZ inference area) and its socio-economic characteristics. IAP is the dependent variable in the model and TAZ socio-economic data measuring parking demands are the independent variables. Because no employee parking subsidy survey was conducted, it is impossible to estimate the out-of-pocket cost by different trip purpose and period and thus it is assumed that every driver coming to a TAZ faces the same average daily parking price no matter what the trip purpose and period would be. The determination of IAP (the average daily parking price of each TAZ influence area) is based on the posted daily maximum parking prices of all paid-parking facilities as discussed above.

The parking price model developed in this study contains two sub-models: a linear regression model of IAP, and a probit model of future occurrence of paid parking. For TAZs currently with parking prices, the linear regression model is applied to forecast the future prices with the difference method. Several outliers violating the statistical relationship were identified and excluded in the model building process. The model is also applied to the TAZs with outliers as well later on. For TAZs currently with no parking price or zero price for these influence areas (i.e., no parking facilities located within the 0.125 mile buffer zone), a probit model is developed to predict the probability of the occurrence of paid parking zones in the future. If the predicted probability for a TAZ is over a pre-defined threshold, the linear regression model will be applied for this TAZ to determine the future parking price. Thus we have identified three types of zones:

1. zones where the linear regression model is developed
2. zones where the outliers are found
3. zones with no price information or zero price.

Model for IAP

The first model for IAP is in the form of a linear regression. The independent variables (e.g., employment densities) used in the model were transformed to approximate the linearity. The square roots of various parking demand variables are used as independent variables. The use of square roots is based on the observation that the increase in price (for per unit increase in the independent variables) gradually diminishes as the independent variables get larger. By taking the square root of the independent variables, an approximate linear relationship between IAP and the parking demands was obtained.

The independent variables used in the model are the TAZ characteristics measuring parking demands. Number of employments, floor areas of office and retail land uses, zonal accessibility, and the parking capacity are all candidates of parking demand estimators. After carefully examining the relationships between IAP and all the available variables (e.g., socio-economical and land use data), it was found that employment densities (i.e., service, retail, other, and total employments) are some of the more significant variables in the relationships (parking capacity variable is also a very significant variable). The significance is determined by the amount of explained price variation when a combination of parking demand variables is included in a regression model. IAP is found positively related to employment densities. The higher the employment densities of a TAZ are, the higher the

IAP is. Among the four types of employment densities, service and retail are generally more significant than the other two (i.e., Other and Total employment).

In their relationship with IAP, land use variables were also found significant. However, it was determined that variables of office and retail land uses derived from the 1993 land use file would not be used in the model, because no specific floor area ratios (i.e., the ratio of built floor area to land area) can be found to convert retail and office land areas to floor areas. In addition, the 1993 land use file may be out-of-date in areas that have been under continuous development (e.g., Orange County).

Although the parking capacity is also highly related to parking price, it was decided for this study that this variable will not be used in the final model, because forecasts of parking capacity are not available. Auto and transit accessibility indicators are not significant explanatory variables of average daily parking prices.

Based on the influence area method, we find that there are 356 TAZs with non-zero paid parking. 33 of them were identified as outliers in the model building process. These outliers are mainly of two distinct types: high-priced TAZs that contain only one parking facility in isolated areas (i.e., no other TAZs in the vicinity have paid parking), and TAZs that do not contain parking facilities but were assigned a very low parking price from TAZs next to it. The former is excluded because the pricing mechanism of such TAZs is likely determined by the parking facility itself without reflecting the actual demand conditions. The latter is excluded because only a small portion (i.e., those located near the borders of TAZs) of employees working at such TAZ (i.e., with no parking facilities) may pay for parking. The majority of such TAZs are actually covered with free parking prices.

The final linear regression model is given as follows with statistics in Table 6:

$$IAP_z = -0.111 + 1.125 * SQ\_SEVA_z + 0.548 * SQ\_RETA_z$$

where,
IAP_z = an average daily parking price (in dollars) of the influence area of TAZ z;
SQ_SEVA_z = a square root of service employment density of TAZ z;
SQ_RETA_z = a square root of retail employment density of TAZ z.

TABLE 5: STATISTIC RESULTS OF THE LINEAR REGRESSION MODEL

	Unstandardized Coefficients	Std. Error	t	Significance (Probability> t)
(Constant)	-0.111	.237	-0.468	0.640
SQ_SEVA	1.125	.083	13.567	0.000
SQ_RETA	0.548	.155	3.538	0.000

Number of observations = 323
R^2 = 0.514
Adjusted R^2 = 0.511

The goodness-of-fit measure (R^2) of the model is 0.514, which is a direct result of the heterogeneity in the development patterns of the SCAG region. The planning area covered in the SCAG region is exceptionally wide with various employment sub-centers scattering within the region (Guiliano and Small, 1991). In downtown Los Angeles and the "Wilshire Corridor" (i.e., a strip of TAZ clusters extending from LA downtown to Santa Monica along the Wilshire Boulevard in the City of Los

Angeles), the relationship between IAP and employment densities is more consistent than any other areas in the region. In many other areas (e.g., Orange County, San Fernando Valley) within the SCAG region, paid-parking facilities usually do not cluster like those in downtown or along the Wilshire Boulevard. Many of the parking facilities serve employment centers (i.e., identified from the office and retail land uses in the 1993 Land Use data) that are much smaller than their TAZs in size. Thus, their employment densities based on TAZ areas are "diluted" and the densities could not reflect the true price vs. demand relationship. Figure 6 shows the scatter-gram between the observed IAP (observed price) and the computed IAP (computed price).

The model specification is theoretically sound and results in a model that is parsimonious and easy to forecast (i.e., SCAG regularly produces forecasts of retail and service employment for each TAZ). In fact, no other combination of TAZ independent variables that are forecast-able by SCAG appeared more significant than the final model specification. The two variables included in the model are also statistically significant. With the sets of TAZ variables that are "forecast-able" by SCAG, this model represents the best estimator of IAP for all the TAZs currently with parking prices. In order to avoid the possible over- or under-estimation of the future prices, the difference method is used, which will be described later on. The main characteristic of the difference method is the estimation of the changes in the price rather than the direct price itself.

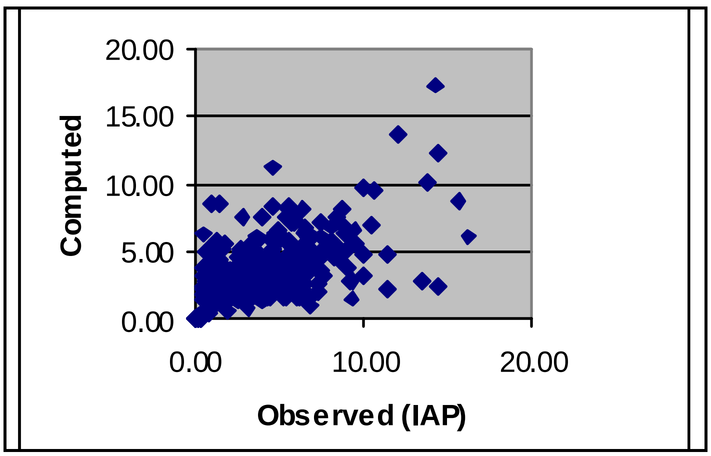

FIGURE 6 - COMPUTED VS OBSERVED PRICES WITH THE MODEL (IAP>0.5)

Model for the Future Occurrence of Paid Parking

For TAZs currently without parking price information or the zero parking price, a model is needed to estimate the probability of occurrence of paid-parking in the future. A probit model using dummy dependent variable was used for this purpose. A dummy variable of "1" is assigned to a TAZ currently with paid-parking and "0" for a TAZ with no price. The general form of the probit model used for this study follows:

$$P(Y=1) = \int_{-\infty}^{\beta' x} \phi(t)\,dt = \Phi(\beta' x)$$

where,

P = probability of having a paid-parking
Y = dummy dependent variable of paid-parking occurrence
x = vector of employment densities
β = vector of parameters
$\varphi(.)$ = density function of standard normal distribution (has a mean of zero and a standard deviation of one)

Φ (.) = cumulative standard normal distribution

The set of parameters β reflect the impact of changes in x on the probability of paid parking occurrence. Following the first model, square roots of service and retail employment densities are used as components of x. Except for the outliers identified, all of the TAZs in SCAG regions were used in the estimation of the probit model. The final specification and results of maximum likelihood P estimation of the probit model (see Table 6) follows:

$$P(Y = 1) = \Phi(-2.681 + 0.603 * SQ\_SEVA + 0.596 * SQ\_RETA)$$

TABLE 6: STATISTICS FOR THE PROHIBIT MODEL

	Unstandardized Coefficients	Std. Error	z (Coefficients/ Std Error)	Significance (Probability> z)
(Constant)	-2.681	0.0836345	-32.062	0.000
SQ SEVA	0.603	0.0443483	13.589	0.000
SQ RETA	0.596	0.0761756	7.824	0.000

Number of observations = 3158
Likelihood Ratio χ^2 (with 2 degrees of freedom) = 651.21
Probability > χ^2 = 0.0000
Log likelihood = -716.73444

The likelihood ratio χ^2 statistic of the maximum likelihood estimation indicates that the model is significantly different from an unrestricted one.

By the convention of probit models, the paid-parking is to occur at a TAZ when the predicted probability of occurrence for the TAZ is greater than 0.5. However, in this study, the threshold probability for paid-parking occurrence is set as 0.6, which is approximately the probability predicted for TAZs with average daily parking prices ranging from 6 to 7 dollars. The justification is that, when a new paid-parking facility is built, the daily parking price usually has to be set at a certain level to absorb the construction cost. To determine the threshold price, the SCAG parking survey data were examined and the median (of 835 parking facilities) daily maximum price of 6.75 dollars was used as the minimum price level for paid-parking to occur. Thus, if the predicted probability for a TAZ is over the threshold of 0.6, the average daily price model will be applied for this TAZ to determine the future daily parking price.

Conclusion

In this section, TJKM identifies three zone clusters and two sets of models. The linear regression model is used for the first and second clusters, while the prohibit model is used for the third cluster.

FORECASTING METHODS

In this section, we use the future socio economic data and apply two models with the forecasting method (difference method) for estimating the change of TAZ prices.

Future Data Preparation

Forecasts of TAZ level socio-economic data for the years 2010 and 2025 were provided by SCAG. The numbers of 2010 and 2025 retail and service employment were each divided by TAZ areas to obtain the densities of retail and service employment.

Difference Method Procedure

For first and second clusters, the future parking price ($PredictPrice_{z(future\ year)}$) is the difference between the future model price ($IAP_{z(future\ year)}$) and the existing model price $IAP_{z(existing\ year)}$ plus the observed parking price (IAP'z(existing year)) as shown below:

$$PredictPrice_{z(future\ year)} = IAP_{z(future\ year)} - IAP_{z(existing\ year)} + IAP'_{z(existing\ year)} \quad \text{if } IAP'_{z(existing\ year)} > 0.$$

Probit Method Procedure

For the third cluster, the future parking price (PredictPricez$_{z(future\ year)}$) is the future model price (IAP$_{z(future\ year)}$) if the probability of having a paid-parking (P)is larger than 0.6, as shown below:

$$PredictPrice_{z(future\ year)} = IAP_{z(future\ year)} \quad \text{if } P > 0.6.$$

Since there is no information on the existing parking prices, IAPz(existing year) would be best estimator of the existing price and we assume that if IAP'z(existing year)=0, then IAPz(existing year)=0, thus the above equation is the difference method.

All these data and the model equations can be found in the APPENDIX A.

Forecasting Results

The detailed numerical results of $PredictPrice_{z(future\ year)}$, and for the observed price $IAP'_{z(existing\ year)}$ and computed prices $IAP_{z(existing\ year)}$ of existing year, future computed price $IAP_{z(future\ year)}$ and parking price PredictPrice$_{z(future\ year)}$ of future years 2010 and are provided in APPENDIX B. Here we provide several results of the parking prices.

Table 7 shows statistics of the existing and future prices by area types. We observe that there are less changes in prices in the current high employment density area such as Core Area, CBD than the low employment area now days such as Rural Area. There will be more zones for Urban Business District, Urban Area and Suburban Area with positive prices in the future years, while the number zones with positive prices in the future years in Core Area, Central Business District and Rural Area remain the same. Figure 7 shows the locations of TAZs with positive prices for the existing year, year 2010 and year 2025. Figure 8 depicts the parking prices for existing, year 2010 and year 2025 in southern LA. area. It is observed that the in downtown LA the prices do not change since the employment densities will not change.

TABLE 7: STATISTICS OF THE EXISTING AND FUTURE PRICES BY AREA TYPE

AreaType	Core Area	Central Business District	Urban Business District	Urban Area	Suburban Area	Rural Area
Years	Count/Min/Mean/Max	Count/Min/Mean/Max	Count/Min/Mean/Max	Count/Min/Mean/Max	Count/Min/Mean/Max	Count/Min/Mean/Max
Exisiting	6/8.09/12.13/15.62	40/0.90/5.97/13.90	158/0.11/3.74/16.26	117/0.07/2.46/14.49	27/0.13/2.42/8.57	7/0.08/1.53/6.87
Exisiting_Model	6/5.37/10.53/17.35	40/2.13/6.18/10.09	158/1.10/3.80/11.17	118/0.85/2.45/5.93	27/0.57/1.64/4.63	7/0.40/0.96/1.84
2010	6/8.32/12.42/15.86	42/1.79/6.54/14.63	168/0.37/4.13/17.12	124/0.16/3.95/14.79	29/0.20/2.91/8.96	7/0.20/1.90/6.95
2025	6/8.38/12.55/15.98	42/1.79/6.54/14.63	186/0.80/4.54/17.72	124/0.76/3.44/14.79	29/0.77/3.04/8.96	7/0.29/2.19/6.99

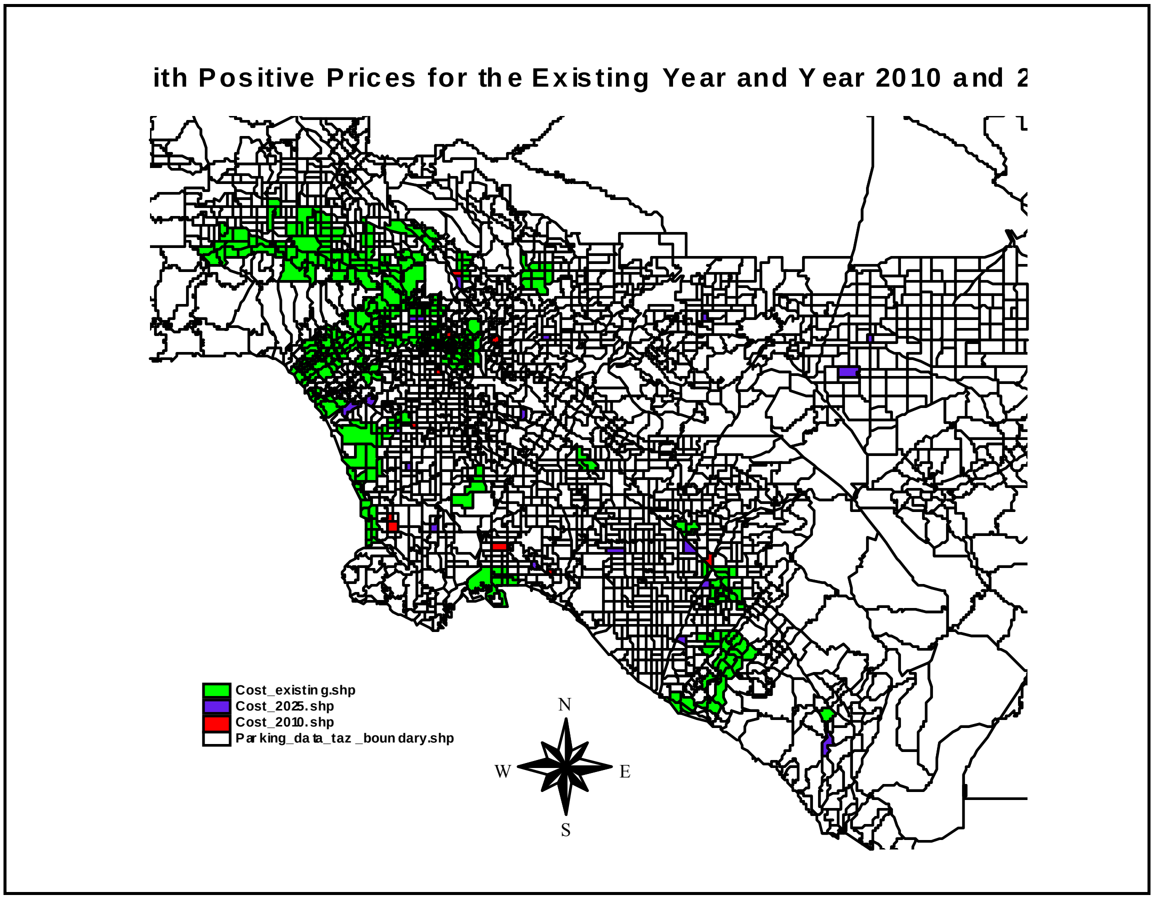

FIGURE 7 - PARKING PRICES OF EXISTING, 2010 AND 2025 IN LOS ANGELES

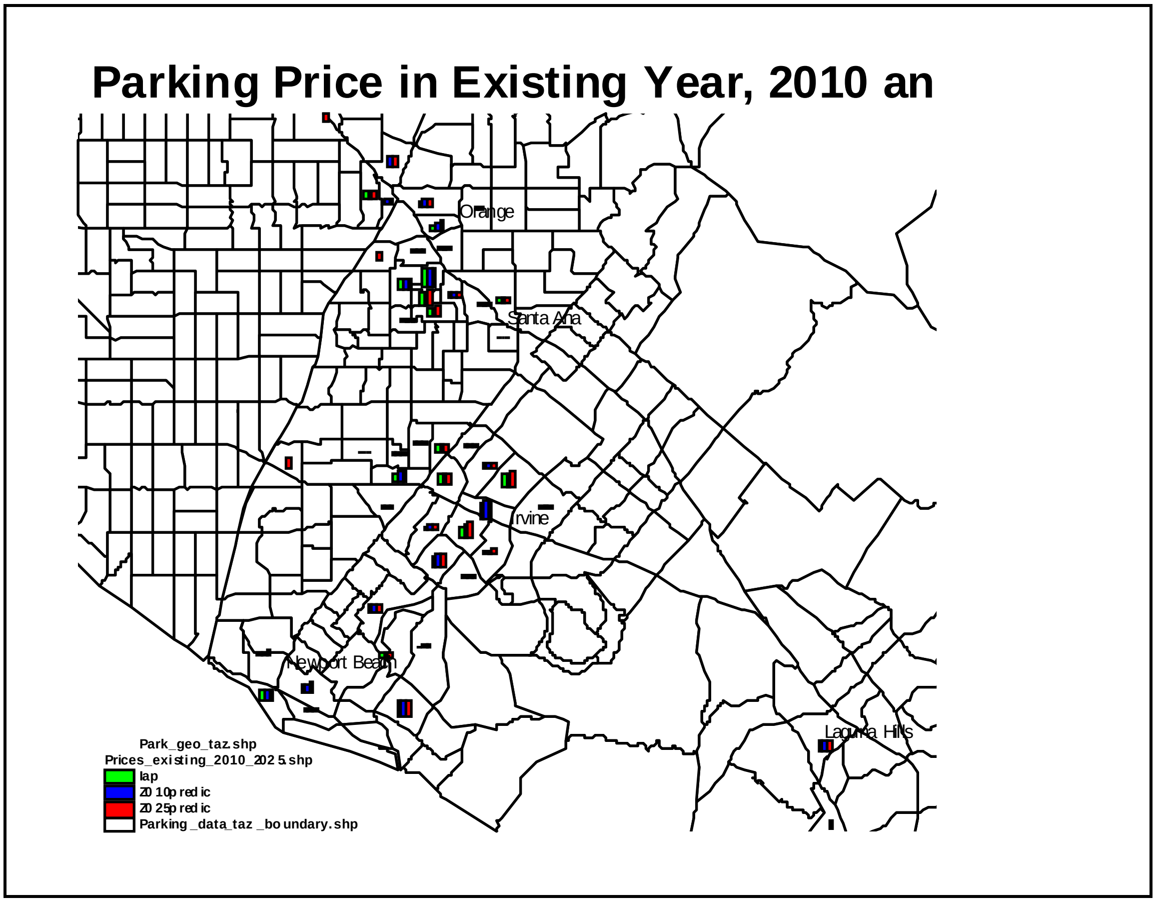

FIGURE 8 - PARKING PRICES OF EXISTING, 2010 AND 2025 IN SOUTH LOS ANGELES AREA

Future Improvements

In this model, we assume the same fixed parking price for all travelers to a zone, based on observed parking prices (IAP) in the zone. This assumption may be reasonable in a large regional demand forecasting model. Thus this model is operational for SCAG.

However, we do see that not only does the parking price vary within a zone, but many travelers, especially commuters to work, have subsidized parking available and may have no cost. Based on this observation, TJKM recommends developing a parking price model that can estimate parking price for all travelers based on characteristics on the parking demand at the facility or the block level as indicated in US DOT (1994). This would require many different types of data. While it is necessary to make a further investigation on this direction, currently the data available to SCAG cannot support this type of investigation but it may be possible in the future.

Facility-Based Method

In this project, TJKM investigated a possible parking price model at the individual facility level with the TAZ-based socio-economic and demographic data. In order to estimate the potential parking demand around a facility, the parking facility shape file was overlaid on the TAZ shape file. Two sets of aggregate measures of employment within a certain radius of a parking facility were developed. The first set measures were derived from a 0.25-mile radius of a parking facility and the second set from a 0.125-mile radius. The way of aggregating zonal employment for the circle around a parking facility was measured first by find all the TAZs that are within the circle. Then, the maximum, minimum, and average of the number of employment of these TAZs were calculated and used to estimate the magnitude of employment around the parking facility.

The daily maximum prices of individual parking facilities were included in the regression models as dependent variables and the overlay aggregate variables were used as the independent variables. Due to inconsistency in the resolutions of dependent variable and independent variables (disaggregate vs. aggregate), no significant relationships were found. If socio-economic data are available at a finer resolution (e.g., Census Block), an individual facility-based model may be achieved, which should offer a more precise estimation of parking price variations. Based on the discussion with SCAG staff on the availability of socio-economic data at the block level, it seems feasible for SCAG to develop this kind of data in the near future. Thus TJKM recommends developing a parking model based on parking facility and block level, and then aggregating these disaggregated prices into TAZ prices.

Other Factor Specific Prices

There are many other factors that would affect the parking prices. They can include the time periods, trip purposes, employer parking subsidy, out-of-pocket cost, free parking space, walk time from the facilities to the final destinations. However, the available data for the project is not sufficient to determine if these factors are significant and logical. For example, there is no information about prices by AM and PM periods and the travel purposes, since the SCAG last parking price survey was in fact a supply related survey with no information on the demand. Parking prices may change due to the pricing mechanism for different types of customers and employer subsidy. It may be argued that the prices may be different for different periods. However there is no evidence to justify this based on the current available data.

With more data on the demand of the parking and real costs to the customers, it is possible to estimate the out-of-pocket cost to the customers instead of just parking prices for the existing condition. Again even with these data, it would be difficult to estimate these information for future years, since SCAG does not provide these data for the future years.

General Summary

In this project TJKM developed a comprehensive GIS data base, and performed the statistical data analysis. Based on the literature review, TJKM developed a SCAG parking price model to estimate the daily average maximum prices (IAP) for the future years using a combination of the GIS technology, the data-mining tool, statistical regression method, the difference method and the probit method. The model is validated with the SCAG parking supply survey. The future parking prices are estimated as well.

STUDY PARTICIPANTS

TJKM Transportation Consultants:

Jia Hao Wu, Ph.D., Project Manager and Modeler
Gary Kruger, P.E., Principal in Charge
Ming Lee, Ph.D., Transportation Engineer and Modeler
Ki Kim, Transportation Engineer

Subconsultant:

Shuguang He, INRO Solutions

SCAG:

Deng Bang Lee, Ph.D., SCAG Project Manager
Hong Kim, Modeler
Teresa Wang, Modeler
Guoxiong Huang, Ph.D., Modeler
Paul Burke, GIS Specialist

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APPENDIX A: ATTACHED FILES

1. Integrated GIS shape files
   a. Parking_data_facility_prices_bar.shp. It is a cleaned parking facility file with additional fields:
      - AMP for the adjusted minimum proce;
      - AMT for the adjusted minimum time, and; and
      - ADM for adjusted daily maximum price.

   b. Parking_data_taz_boundary.shp. It includes the original SCAG socio-economic data and the TJKM' computed data such as
      - IAP for existing price;
      - ModelPrice(dollar) for the existing model price;
      - 2010PredictPrice for the 2010 price; and
      - 2025PredictPrice for the 2015 price.
2. Excel file
   a. TransferForecast_SCAG. It provides the computational results including probit model, the parking model, and
      - Square roots of the service employment densities and the retail employment densities for the existing year and year 2010 and 2025
      - Model parameters
      - IAP for existing price;
      - ModelPrice(dollar) for the existing model price;
      - 2010PredictPrice for the 2010 price; and
      - 2025PredicPrice for the 2015 price.

APPENDIX B: TAZ PARKING PRICES (EXISITNG, 2010 AND 2025)